CLAIMS

1. An optical device which includes a photonic crystal comprising:

a first member which has a distribution of refractive index decreasing with distance from an optical axis of incident light as to a first direction perpendicular to the optical axis; and

a second member which is substantially periodically placed within the first members as to a second direction different from the first direction.

2. The optical device according to claim 1, wherein the distribution of the refractive index decreasing with distance from the optical axis is the distribution of the refractive index decreasing in a direction other than the direction of periodic placement of the second member.

3. The optical device according to claim 2, wherein the incident light is to be substantially confined inside the photonic crystal as to the first direction by so determining:

(a) the distribution of the refractive indexes of the first member as to the first direction;

(b) a thickness of the photonic crystal as to the first direction;

(c) a wavelength of the incident light; and

(d) a beam spot radius which relates to the first direction inside a light incident end of the photonic crystal entered by the light of the incident light.

4. The optical device according to claim 3, wherein:

the photonic crystal is in a film form;

the first direction is a direction of a film thickness of the film form; and

the second direction is a direction parallel to a film surface of the film form.

5. The optical device according to claim 4, wherein the distribution of the refractive indexes of the first member which relates to the direction of the film thickness is more precipitous than a predetermined distribution function determined based on a thickness W which relates to the direction of the film thickness of the photonic crystal, a wavelength λ of the incident light and a beam spot radius ω_1 which relates to the direction of the film thickness inside the light incident end of the incident light.

6. The optical device according to claim 5, wherein the predetermined distribution function is substantially given by the following quadric which includes a refractive index distribution constant g and a maximum value n_1 of the refractive index which relates to a y-coordinate about the direction of the film thickness in reference to the optical axis.

[Formula 1]

$$n(y) = n_1\left(1 - \frac{g^2 y^2}{2}\right)$$

7. The optical device according to claim 5, wherein the predetermined distribution function is substantially given by the following function which includes a refractive index distribution constant g, a flat portion constant a and a maximum value n_1 of the refractive index which relates to a y-coordinate about the direction of the film thickness in reference to the optical axis.

[Formula 2]

$$n'(y)=\begin{cases} n_1\left\{1-\dfrac{g^2(y+a)^2}{2}\right\} & (y \le -a) \\ n_1 & (-a \le y \le a) \\ n_1\left\{1-\dfrac{g^2(y-a)^2}{2}\right\} & (a \le y) \end{cases}$$

8. The optical device according to claim 6 or 7, wherein the refractive index distribution constant g substantially satisfies the following formula.

[Formula 3]

$$g \ge \frac{2\lambda}{\pi\omega_1 W}$$

9. The optical device according to claim 5, wherein a curvature radius of a wave front of the incident light at the light incident end is substantially infinite.

10. The optical device according to claim 9, wherein the beam spot radius ω_1 is substantially a half of the thickness W.

11. The optical device according to claim 9, wherein the film thickness varies at a predetermined location.

12. The optical device according to claim 11, wherein the incident light is to be leaked outside the photonic crystal at the predetermined location as to the film thickness direction by so determining:

the distribution of the refractive indexes of the first member as to the film thickness direction;

the thickness W of the photonic crystal as to the film thickness direction;

a wavelength λ of the incident light; and

a beam spot radius ω_1 inside the light incident end of the incident light as to the film thickness direction.

13. The optical device according to claim 9, wherein a substantially periodical placement of the second member varies at a predetermined location.

14. The optical device according to claim 13, wherein the predetermined location is the location where the beam spot radius of the incident light inside the photonic crystal which relates to the film thickness direction takes a maximum value or a minimum value.

15. The optical device according to claim 13, wherein the predetermined location is the location continued from the light incident end to a light outgoing end of the photonic crystal which emits the light and has no second member substantially placed therein.

16. The optical device according to claim 9, wherein the second member is air placed by using holes which extend in the film thickness direction.

17. The optical device according to claim 16, further comprising a substrate which holds the photonic crystal, wherein the holes are extending to the substrate side.

18. The optical device according to claim 3, further comprising an inducing portion which induces the incident light to the light incident end.

19. The optical device according to claim 18, wherein the inducing portion converts the incident light to render the curvature radius of the wave front at the light incident end substantially infinite.

20. The optical device according to claim 18, wherein the inducing portion converts the incident light to have a beam waist formed at the light incident end.

21. The optical device according to claim 18, wherein the inducing portion converts the incident light to render the beam spot radius which relates to the first direction inside the light incident end substantially a half of the thickness of the photonic crystal which relates to the first direction.

22. The optical device according to claim 3, wherein the first member is a member which has a siloxane structure distributed correspondingly to the refractive index distribution in a base material of which main component is polysilane.

23. A manufacturing method of a photonic crystal slab which includes a first member which has a distribution of refractive index as to a first direction perpendicular to an optical axis of incident light and a second member substantially periodically placed within the first member as to a second direction different from the first direction, the method comprising:

a first step of supplying a base material of a predetermined thickness of which main component is polysilane;

a second step of causing an oxidation reaction of the polysilane in the supplied base material and controlling a degree of progress of the oxidation reaction in reference to the thickness direction so as to form the distribution of the refractive index decreasing with distance from the optical axis; and

a third step of forming the second member in a step before or after the second step.

24. The manufacturing method of a photonic crystal slab according to claim 23, wherein the distribution of the refractive index decreasing with distance from the optical axis is the distribution of the refractive indexes reduced in a direction other than the direction of the periodical placement of the second member.

25. The manufacturing method of a photonic crystal slab according to claim 24, wherein:

the first direction is a direction of thickness of the base material; and

the second direction is a direction parallel to a surface of the base material.

26. The manufacturing method of a photonic crystal slab according to claim 25, wherein:

according to the second step, the distribution of the refractive indexes is generated by irradiating the base material with ultraviolet light from both sides thereof; and

an amount of the ultraviolet light irradiation is controlled to have a predetermined standard satisfied by a state of the distribution of the refractive indexes.

27. The manufacturing method of a photonic crystal slab according to claim 26, wherein:

according to the first step, the base material is applied on a predetermined substrate;

according to the second step, the ultraviolet irradiation and heat treatment are performed to the applied base material to harden the base material; and

according to the third step, cylindrical holes as the second members are periodically placed on the hardened base material by using a mold or performing etching.

28. The manufacturing method of a photonic crystal slab according to claim 27, wherein the predetermined standard is that the distribution of the refractive index is more

precipitous than a predetermined distribution function determined based on a thickness W which relates to the direction of the film thickness of the photonic crystal slab, a wavelength λ of the incident light and a beam spot radius ω_1 which relates to the direction of the film thickness inside a light incident end of the incident light.